Fallout of reactive nitrogen

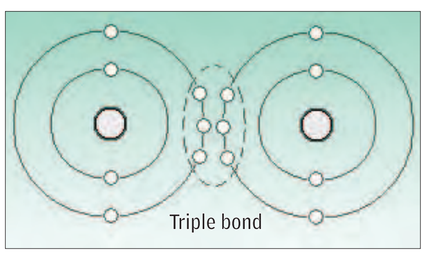
THE RISING POPULATION WOULD DO US IN WITHOUT ANY HELP FROM GLOBAL WARMING, SAYS **S ANANTHANARAYANAN**

Human activity and the use of fossil fuel have created a spectre that is leading to the melting of polar ice, rising sea levels, changing climate and demographic upheaval. But even if alternate fuels were found and warming were reversed, the effects that the nutrition demands of a rising population have on the environment could make survival difficult before the end of the century.

A team at the Potsdam Institute for Climate Impact Research, Germany, and the International Centre for Tropical Agriculture, Colombia, reports in the journal *Nature Communications* the results of model simulations of the rise in levels of reactive nitrogen — that is, nitrogen in forms other that the inert kind that forms a large part of the atmosphere. This form of nitrogen, while necessary for life, can make itself unsustainable when it is in excess. While the levels of reactive nitrogen, which is required for agriculture, are already rising much faster than what is safe, the study examines where we are likely to land by 2050 if we continue with "business as usual", or even if we take pollution mitigating measures.

Nitrogen gas is abundant and makes up 78 per cent of the atmosphere. Necessary for all known forms of life, it is there in the amino acids, of which proteins are made; it is there in the DNA and RNA; and in plants it is there in chlorophyll. But it is not the nitrogen in the atmosphere that living things can make use of. Gaseous nitrogen consists of *pairs of nitrogen atoms* bonded as diatomic molecules. The nitrogen atom has three unpaired outer shell electrons, and these pair up when the molecule forms. This *triple bond* is a very strong one and it takes energy to get the nitrogen atoms to separate and combine with other chemical groups. The nitrogen in the atmosphere is, thus, inert and hardly reacts with anything. This, incidentally, is the reason some foodstuffs are sealed with nitrogen in the wrapping to prevent decay or spoiling.

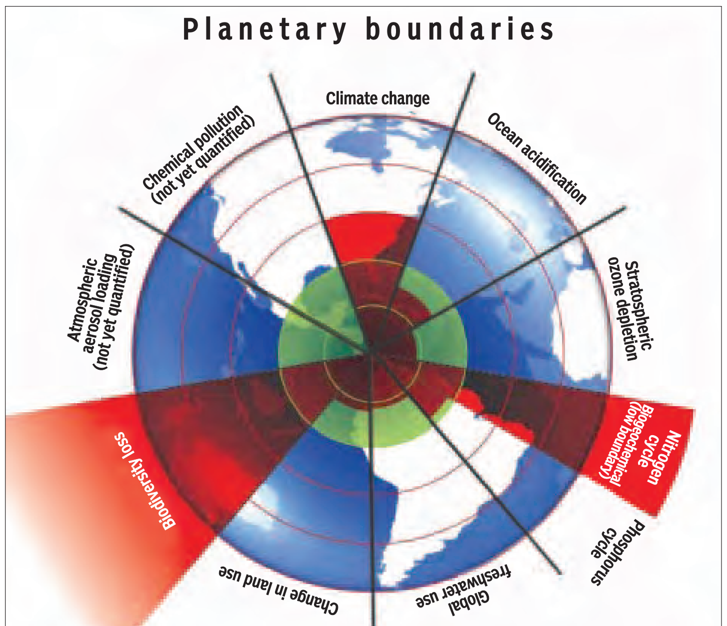
The chemical bond in the ordinary nitrogen molecule then needs to be broken, to get nitrogen into other compounds, which is to create a form of *reactive nitrogen* that is ready to combine and form other molecules, which are important for life processes. This process, called *nitrogen fixation*, happens naturally in thunderstorms when lightning strikes and, more commonly, by action of bacteria in the roots of leguminous plants, which are plants like the pea plant or alfalfa. Agriculture uses up this nitrogen and depletes the soil, which then needs to be left fallow to regenerate. Or legumes need to be planted in alternate seasons, or sources of reactive nitrogen need to be added in the form of manure or chemical fertiliser.



But too much of reactive nitrogen can be a menace, too. As the normal nitrogen gas is so stable, or of very low energy condition, the nitrogen in nitrogen compounds is always eager to break free and get back to the happy, diatomic molecule state. Free reactive nitrogen, more than what plants need, thus causes serious damage to health and the ecology. In the air, it raises ozone levels and causes respiratory ailments, even cancer. It can come down as acid rain and damage buildings, acidify the soil or cause lopsided plant growth, leading to nutrient imbalance and loss of biodiversity. It can render groundwater or surface water unfit for drinking, affecting the oxygen balance in infants, which leads to *blue baby syndrome*. When it washes into waterways, it nourishes algae, which feed bacteria, which use up the store of oxygen. And then, nitrous oxide, one of the reactive nitrogen forms, is a greenhouse gas nearly 300 times worse than carbon dioxide.

For centuries, till the industrial revolution, the supply of reactive nitrogen was balanced in the ecosystem and was able to stay within narrow limits for humankind to flourish for all of 10,000 years, the so called *Holocene* period. But the last many decades have seen rising a population, human prosperity and activity and greatly increased agriculture. For increased agriculture, the natural sources of fixed nitrogen are not sufficient and chemical fertiliser has been made in factories. The Haber-Bosch process revolutionised agriculture by creating ammonia from nitrogen and then huge quantities of ammonia-based fertiliser. As demand for foodgrains was soaring, farmers used fertiliser liberally and costs were even subsidised by the state.

The trouble with the use of chemical fertiliser is that the great part of the chemicals do not stay to be used by the plant but get washed off by irrigation water and enter the groundwater or waterways. And then there are other sources of reactive nitrogen, in automobile exhaust and the refuse of humans and lifestock! It is estimated that the total flow of reactive nitrogen into the ecosystem is now about 185 million tonnes, as against some 25 million in 1950. And as the world population and aspirations rise, this figure would also rise and aggravate an already alarming situation.



The green ring represents the limit that has been breached by climate change, loss of biodiversity and the addition of reactive nitrogen and phosphorus.

In a paper in the journal *Nature* in 2009, J Rockström and colleagues of the Stockholm Resilience reported their study of the earth system processes that were under threat due to human activity and defined the limits that needed to be respected to avoid disastrous and irreversible environmental changes. Of the nine such *planetary boundaries* identified, three had already been breached and active nitrogen, here the limit was 35 million tonnes a year, was one. Reviews of the scale of nitrogen lows have since been made and there are outline assessments of future levels, but without a comprehensive inclusion of available mitigation measures.

Mitigation

The current study by the Potsdam and Columbia team examines the rise in levels till 2050 by modelling land use and the nitrogen budget under different assumptions of consumption patterns and production technology. The result, after considering the estimated population increase, is that nitrogen sources would increase from 185 million tonnes to 232 million tonnes. The study then considers the mitigating efforts that could be made — reduced household food waste and recycling of food waste and sewage as fertilisers; lower share of animal-based calories in diets; efficient livestock management by improved feeding and higher recycling share for animal manure; and efficient fertilisation of fields.

The estimated result of these measures is that the reactive nitrogen entering the environment in 2050 could come down to 95 million tonnes, in place of 232 million tonnes a year, with excellent overall efficiency of nutrient use being attained. But even this level is well above the recommended 35 million tonnes.

While a degree of pollution hence appears inevitable, the paper notes that the impact of pollution depends not only on how much active nitrogen, but also where the level is high as also the vulnerable ecology and population. Adaptation to high levels would thus be the way to go, with higher levels being allowed where the risks are lower. And for all that, there is need for a global perspective, lest centres of pollution only shift position, and to tackle pollutants that have a far-reaching impact.

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HIGH TURNOVER RATE

TAPAN KUMAR MAITRA EXPLAINS THE KEY ASPECTS OF MRNA METABOLISM

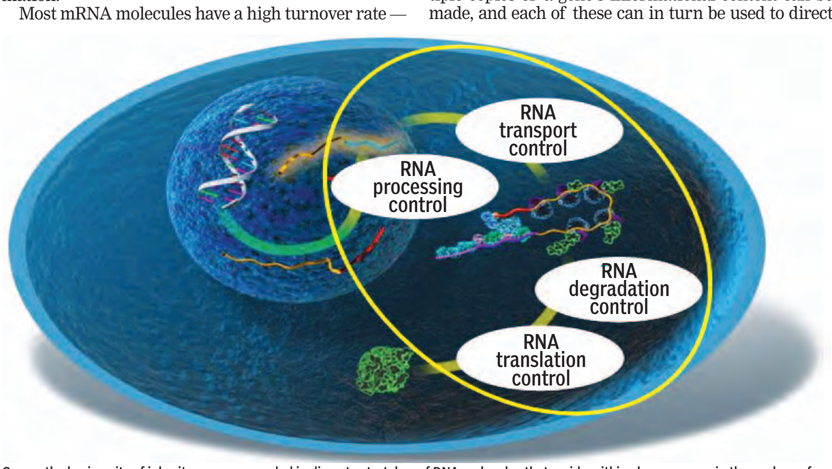
We should note two key aspects of mRNA metabolism that are important to our overall understanding of how molecules in this category behave within cells. These are the short life span of most mRNAs and their ability to amplify genetic information.

Most mRNA molecules have a high turnover rate — that is, the rate at which they are degraded and then replaced with newly synthesised versions. In this respect, mRNA contrasts with the other major forms of RNA in the cell, rRNA and tRNA, which are notable for their stability.

Because of its short life span, mRNA accounts for most of the transcriptional activity in many cells, even though it represents only a small fraction of the total RNA content. Turnover is usually measured in terms of a molecule's half-life, which is the length of time required for degradation of 50 per cent of the molecules present at any given moment. The mRNA molecules of bacterial cells generally have half-lives of only a few minutes, whereas the half-lives of eukaryotic mRNAs range from several hours to a few days.

Since the rate at which a given mRNA is degraded determines the length of time it is available for translation, alterations in mRNA life span can affect the amount of protein a given message will produce. Regulation of mRNA life span is one of the mechanisms by which cells exert control over gene expression.

Because mRNA molecules can be synthesised again and again from the same stretch of template DNA, cells are provided with an important opportunity for amplification of the genetic message. If DNA gene sequences were used directly in protein synthesis, the number of protein molecules that could be translated from any gene within a given time period would be strictly limited by the rate of polypeptide synthesis. But in a system using mRNA as an intermediate, multiple copies of a gene's informational content can be made, and each of these can in turn be used to direct the synthesis of the protein product.



Genes, the basic units of inheritance, are encoded in discrete stretches of DNA molecules that reside within chromosomes in the nucleus of a cell. An intermediate form of the genetic information, called messenger RNA (mRNA), is synthesised in a process known as transcription. mRNA then acts as a critical mediator of gene expression, carrying the necessary information from the "library" of genes stored in the cellular DNA to the machinery that makes proteins.

As an especially dramatic example of this amplification effect, consider the synthesis of fibroin, the major protein of silk. The haploid genome of the silkworm has only one copy of the fibroin gene, but about 10^4 copies of fibroin mRNA are transcribed from the two copies of the gene in each diploid cell of the silk gland. Each of these mRNA molecules, in turn, directs the synthesis of about 10^5 fibroin molecules, resulting in the production of 10^9 molecules of fibroin per cell — all within the four-day period it takes the worm to make its cocoon! Without mRNA as an intermediate, the genome of the silkworm would need 10^4 copies of the fibroin gene (or about 40,000 days!) to make a cocoon.

Significantly, most genes that code for proteins occur in only one or a few copies per haploid genome. In contrast, genes that code for rRNA and tRNA are always present in multiple copies. It is advantageous for cells to have many copies of genes whose final products are RNA (rather than protein), because in this case there is no opportunity for amplifying each gene's effect by repeated translation.

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Verge of catastrophe

HUMANS HAVE CAUSED EXTINCTION RATES TO INCREASE BY UP TO 10,000 TIMES. **TOMAS JIVANDA** REPORTS

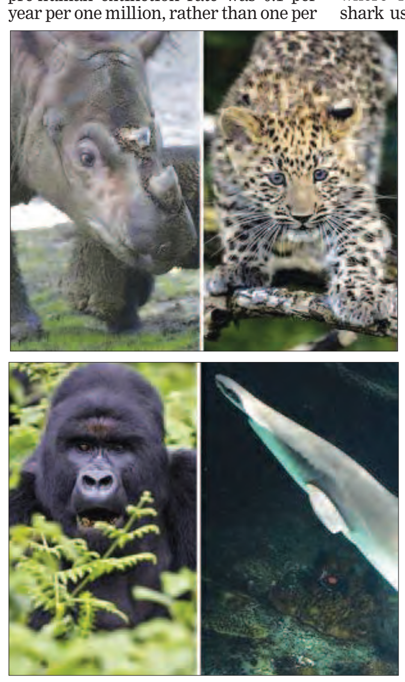
Humanity is responsible for speeding up the natural rate of extinction for animal and plant species by up to 10,000 times, as the planet is on the brink of a dinosaur-scale sixth mass extinction, a new study has warned.

Species are disappearing around 10 times faster than is widely believed in the scientific community, while in pre-human times extinction rates were slower than previously thought, researchers from Duke University in the USA said. "We are on the verge of the sixth extinction," lead author, biologist Stuart Pimm, said. "Whether we avoid it or not will depend on our actions."

Praised by independent experts as a landmark report, it focuses around calculating a "death rate" of how many species become extinct each year out of one million species. Analysing the latest research, the team concluded that the pre-human extinction rate was 0.1 per year per one million, rather than one per one million, as a previous study led by Dr Pimm in 1995 suggested. Today, the rate is at least 1,000 times greater than the 0.1 figure at 100 extinctions per year per million species, but could be up to 1000 per one million, Dr Pimm said. Although a combination of numerous factors was responsible for the acceleration in disappearance of species, the biggest was habitat loss caused by humans, he and co-author Clinton Jenkins from the Institute of Ecological Research in Brazil said.

Other major issues are invasive species introduced by humans crowding out native species, climate change affecting where species can survive and overfishing.

A good example is the buffy tufted-ear marmoset. Dr Jenkins said development in Brazil had decimated its habitat while a competing marmoset had taken over where it lived. The oceanic white-tip shark used to be one of the most abundant predators on earth, but they had been hunted so much that they are now rarely seen, added Dalhousie University marine biologist Boris Worm, who praised the study. "If we don't do anything, this will go the way of the dinosaurs."


The Sumatran rhinoceros (clockwise from top left), Amur leopard, mountain gorilla and white-tip shark are all species at risk.

Other species at great risk include the Sumatran rhinoceros, Amur leopard and mountain gorilla. Pimm and Jenkins did, however, say there was some hope. Both said the use of smartphones and applications such as iNaturalist would help ordinary people and biologists to find species in trouble. Once biologists knew where endangered species were, they could try to save habitats and use captive breeding and other techniques to save the species, they said.

One success story is the golden lion tamarin. Decades ago, these tiny primates were thought to be extinct because of habitat loss, but they were then found in remote parts of Brazil and bred in captivity, and biologists helped set aside new forests for them to live in, Jenkins said. "Now there are more tamarins than there are places to put them."

THE INDEPENDENT

PLUS POINTS

'Tractor beam'

A team of physicists at Scotland's Dundee University has turned science fiction into science fact by creating the first functioning acoustic tractor beam. Until now tractor beams — devices with the ability to attract one object to another from a distance — have only featured in science fiction films, plausible only in the other worlds, planets and galaxies featured in the likes of *Star Trek* and *Star Wars*.

Working with colleagues at Southampton University and Illinois Wesleyan University, researchers from Dundee University have used energy from an ultrasound array to exert force behind an object and pull it towards the energy source. Dr Christine Demore, from the Institute for Medical Science and Technology at Dundee, said, "This is the first time anyone has demonstrated a working acoustic tractor beam and the first time such a beam has been used to move anything bigger than microscopic targets. We were able to show that you could exert sufficient force on an object around one centimetre in size to hold or move it by directing twin beams of energy from the ultrasound array towards the back of the object."

She said that far from being just confined to the realms of science fiction, the technology had significant potential in medicine by targeting and attracting individual cells. "Our research could lead to big advances in the application of ultrasound-based techniques in sectors such as healthcare."

The researchers, together with Dr Gabe Spalding at Illinois Wesleyan University, previously demonstrated that another piece of sci-fi technology, Doctor Who's sonic screwdriver, could also be created using a similar ultrasound array. The results have been published in the scientific journal *Physical Review Letters*.

Solar sails

A new method of space travel is about to get its moment in the sun. Several upcoming missions aim to harness the subtle push of sunlight, using gossamer "solar sails" to cruise through the heavens like boats through the sea. Such propellant-free propulsion could take craft cheaply and efficiently to a variety of destinations, from locations in near-earth space to the edge of the solar system and beyond, advocates say.


Artist's conception of Sunjammer Sail in flight above Earth.

A spacecraft, equipped with a sail 1,300 feet wide, for example, could travel 1.3 billion miles per year, allowing it to escape the sun's sphere of influence in just a decade or so, according to researchers behind the Interstellar Probe, a National Aeronautics and Space Administration concept mission proposed about 15 years ago.

"There's nothing known to us now that could actually attain that kind of a speed using chemical propulsion," said aerospace engineer Bruce Campbell during a presentation with Nasa's Future In-Space Operations working group. Other projects now loom on the horizon, building momentum for the technology.

A big milestone should come in early 2016, when Nasa plans to launch the largest-ever solar sail to space. The $27-million Sunjammer mission, which takes its name from the Arthur C. Clarke story, will use a sail built by California-based company L'Garde that measures 124 feet on a side. The sail, made of an advanced material called Kapton, is just five microns (about 0.0002 inches) thick. It weighs less than 32 kg and packs down to the size of a dishwasher, Nasa officials have said.

Space taxi

A futuristic ship that brings commercial space taxis one step closer to reality, unveiled on 29 May, is the latest pioneering idea from inventor and SpaceX founder Elon Musk. The spacecraft, called Dragon V2, is designed to launch into low earth orbit and send astronauts to the International Space Station, replacing the pricey ships used in the past. The Dragon V2's sleek design has a retooled heat shield that will withstand multiple re-entries, unlike the disposable vehicles used now. The spacecraft also has retractable legs that allow it to land and take off vertically.

"You'll be able to land anywhere on earth with the accuracy of a helicopter," Musk said at a news conference held at the SpaceX headquarters in Hawthorne, California. The ship is designed to land, be quickly refuelled with propellant and launch again. It also would support up to seven astronauts in space for several days, which could make commercial manned missions more feasible.

The Dragon V2 is just one of many futuristic ideas that Musk has dreamed up. Its precursor, Dragon V1, launched its maiden flight in 2010. At the time, only three countries had built spaceships that could enter low earth orbit.